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Woods Hole Oceanographic Institution

U.S. GLOBEC Georges Bank Long-Term Moored Program: Part 1 - Mooring Configuration

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December 2005

Technical Report

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Approved for Distribution:

James F. Lynch, Chair

Department of Applied Ocean Physics and Engineering

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ABSTRACT

As part of the U.S. GLOBEC Northwest Atlantic/Georges Bank program, moorings were deployed on Georges Bank as part of the broad-scale survey component to help measure the temporal variability of both physical and biological characteristics on the Bank. The array consisted of a primary mooring site on the Southern Flank which was maintained for the full 5-year duration of the field program, plus secondary moorings, with fewer sensors and of shorter duration, in the well-mixed water on the Crest and in the cod/haddock spawning region on the Northeast Peak. Temperature and conductivity (salinity) were measured at 5-m intervals, ADCP velocity profiles were obtained with 1-m vertical resolution, and bio-optical packages (measuring fluorescence, optical transmission and photosynthetically active radiation) were deployed at 10-m and 40-m depths. Bottom pressure was measured at the Southern Flank site. The buoy design, sensors and mooring configuration is presented and discussed below, and the data obtained is presented and discussed in an accompanying reports "U.S. GLOBEC Georges Bank Long-Term Moored Program: Part 2 – Yearly Data Summary and Report," and "U.S. GLOBEC Georges Bank Long-Term Moored Program: Part 3 – Data Summary."

I. INTRODUCTION

U.S. GLOBEC (GLobal Ocean ECosystem Dynamics) is part of the U.S. Global Change Research Program. The goal of U.S. GLOBEC (GLOBEC, 1992) is to understand the physical and biological processes controlling the abundance of marine animals in space and time and to use this understanding to predict the effects of climate change on ecosystem dynamics. The Georges Bank GLOBEC program has four main programmatic elements: broad-scale studies (including shipboard, moored, drifter and satellite observations), process-oriented studies, modeling, and synthesis/comparative analysis.

The GLOBEC Long-Term Moored Program deployed moorings at the Crest, Southern Flank and Northeast Peak sites of Georges Bank (Fig. 1, Table 1) to observe the seasonal and interannual variability of the physical (and to a certain extent the biological) properties at these sites. Additionally, CTD sections were taken on deployment and recovery cruises (Fig. 1 and Part 3 Table 14). The long-term moored effort addressed:

1. The spatial and temporal variability of the atmospheric forcing in the Georges Bank region and its relationship to the resulting water properties, stratification and circulation.
2. The variability of the temperature, salinity, and water velocity at the mooring sites.
3. The tides and internal tides, their relation to mixing on Georges Bank.
4. The subtidal wind- and density-driven currents and their relation to the retention of organisms on the Bank.
5. The temporal variability of biological indicators {photosynthetically active radiation (PAR), optical transparency, and chlorophyll-a fluorescence} at the moorings and their relation to the primary production and species abundance as observed from the broad-scale and process studies.

6. The effects of episodic events (storms, warm core rings, etc.) on the physical properties at the mooring sites and the retention and loss of organisms from Georges Bank.

Georges Bank (Fig. 1) is a large, shallow submarine bank that separates the Gulf of Maine from the North Atlantic Ocean. Water on Georges Bank has two primary sources: (a) the cold fresh Scotian Shelf water which enters the Gulf of Maine around Cape Sable and occasionally flows directly across the Northeast Channel onto Georges Bank; and (b) warm saline Slope Water which enters the Gulf of Maine through the deep Northeast Channel. These two sources, together with local runoff, mix to form intermediate water masses that flow onto Georges Bank along its western and northern flank. The permanent shelf/slope front located along the southern shelf-break near the 100-m isobath separates the shelf water over Georges Bank from the more saline Slope Water offshore.

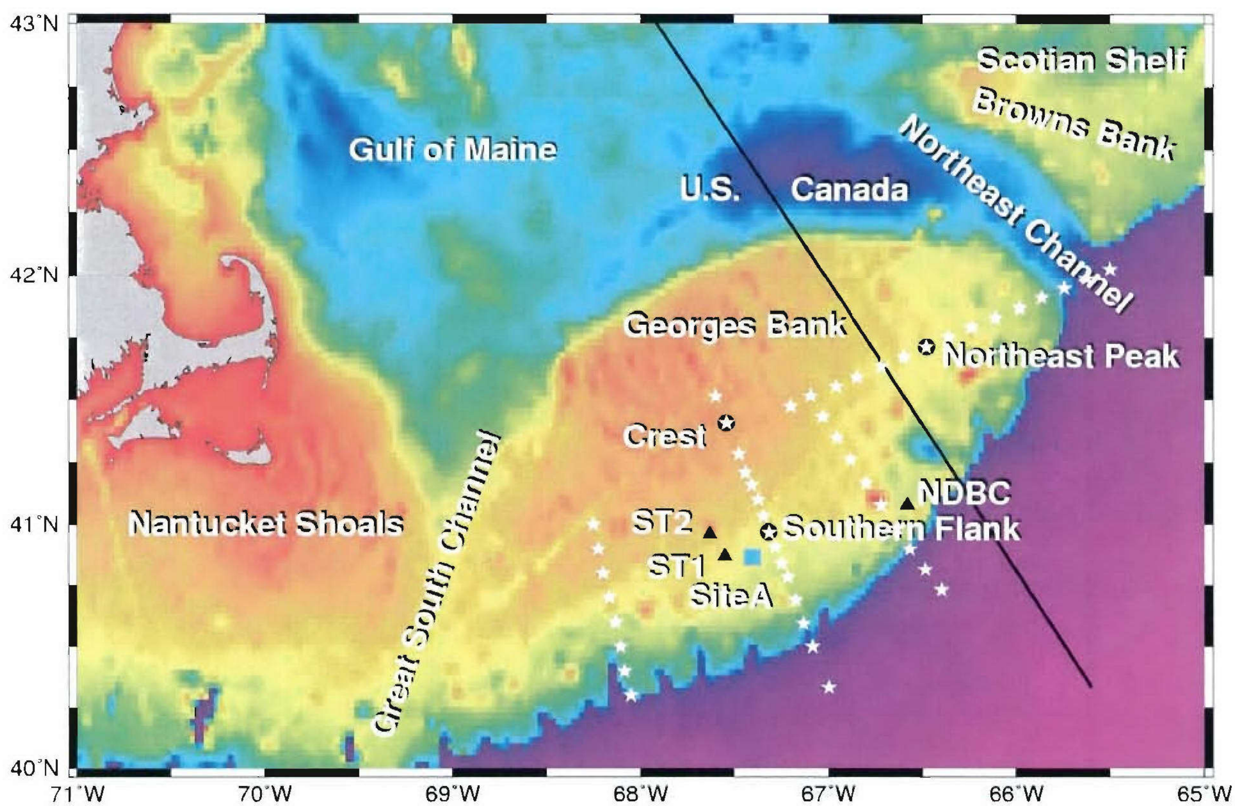


Figure. 1. The GLOBEC Long-Term moorings sites on Georges Bank, (O), and standard CTD stations, (*). Stratification Process mooring sites are also shown as ST1 and ST2 as well as the USGS Long-Term Mooring Site A (□),and NDBC Georges Bank environmental buoy #44011 (Δ). The color indicates the bathymetry, with red the shallowest to violet the deepest.

Currents on Georges Bank are dominated by tides, buoyancy-driven and wind-driven effects. Tidally generated turbulence leads to complete vertical mixing over the central bank and maintains a tidal mixing front located at about the 55-m isobath during the stratified season. Tidal rectification helps to drive a clockwise circulation around Georges Bank. This is more intense along the northern flank where the slope of the bank is the steepest. The strength of this circulation increases with increasing stratification during spring-summer. Moored and drifter

studies show significant recirculation of flow along the Southern Flank northward through the Great South Channel, indicating the partially closed character of the around-bank flow in summer. Wind-driven currents are strongest in winter when strong storms are more frequent.

A number of processes directly influence the survival rate of larval fish. Near-surface advection associated with strong storms, variability in time and strength of spawning, the development of stratification, and the strength and continuity of the around-bank circulation can all affect survival. Warm-core rings can either push Slope Water onto the bank or pull shelf water off the bank, which may enhance or decrease larval-fish survival. To study these effects in the stratified Southern Flank region, a mooring was maintained at the Southern Flank site (Fig, 1, 2 and 3, and Tables 1, 2 and 3) from fall 1994 through summer 1999. Shorter deployments were made for 1 year in the well mixed water inside the tidally-mixed front on the Crest (Fig. 1, 8 and 9, and Tables 1 and 4) and for three years in the cod/haddock spawning region at the Northeast Peak (Fig. 1, 2 and 9, and Tables 1 and 5) at the same depth, and "upstream" of the Southern Flank site.

Table 1. Long-Term Mooring Deployment Positions

Deployed (cruise, date)	Southern Flank	Bottom Pressure	Crest	Northeast Peak
1: OC256, Oct 94	40° 58.096' N 67° 19.173' W		41° 24.413' N 67° 32.485' W	
2. SJ9504, Apr 95 SJ9506, Apr 95	40° 58.15' N 67° 19.18' W		41° 24.561' N 67° 32.538' W	
3. AL9513, Nov 95	40° 58.125' N 67° 19.185' W			41° 42.71' N 66° 28.68' W
4. OC276, Apr 96	40° 58.106' N 67° 19.064' W	40° 58.115' N 67° 19.100' W		41° 42.659' N 66° 28.553' W
5. OC291, Oct 96	40° 58.037' N 67° 19.219' W			41° 43.922' N 66° 32.147' W
6. KN149, Apr 97	40° 57.974' N 67° 19.139' W			41° 43.92' N 66° 32.16' W
7. EN208, Oct 97	40° 58.069' N 67° 19.063' W	40° 58.027' N 67° 19.004' W		
8. OC321, Apr 98	40° 58.058' N 67° 19.089' W	40° 58.088' N 67° 18.998' W		
9. OC331, Oct 98 OC333, Nov 98	40° 57.992' N 67° 18.919' W	40° 57.972' N 67° 19.014' N		41° 43.851' N 66° 32.176' W
10. OC338, Mar 99	40° 58.019' N 67° 19.165' W	40° 58.011' N 67° 19.267' W		
Nominal Position	40° 58' N 67° 19' W	40° 58' N 67° 19' W	41° 24.5' N 67° 32.5' W	41° 44' N 66° 32' W

II. BUOY AND SENSOR CONFIGURATIONS

A. Southern Flank:

1. Site: The Southern Flank site had the highest priority. It was selected to be in the middle of the stratified region between the shelf-slope front (located near the 100-m isobath) and the tidally-mixed front (at about 55 m depth). This region is mixed vertically during the winter, but stratifies with spring-summer warming. The site was in 76 m of water to be inside normal excursions of the shelf-slope front, and yet as far offshore of the tidally-mixed front as possible. The seafloor in the Southern Flank region of Georges Bank from 50 to 120 m is relatively

smooth sand/gravel with some broken shells. Scallop dredge tracks are visible in the sediments throughout the region on side-scan sonar records (Page Valentine, personal communication). No larger features were observed. The site (Fig. 1) was located in the open fishing region that gets year-round fishing activity, and was located to the east of the Stratification Study mooring site (ST1 and ST2) occupied during 1995, and formed one leg of that process-oriented study's array (Alessi et al., 2001). The currents at the site are strongly tidal due to the Gulf of Maine/Bay of Fundy near semidiurnal tidal resonance that causes stronger tidal currents over Georges Bank, especially over the Crest and through the Northeast Channel (near the Northeast Peak mooring).

The Crest and Northeast Peak mooring configurations were subsets of the Southern Flank mooring, which will be discussed in detail first. The Southern Flank mooring configuration evolved during the program, but Fig. 2 shows the standard configuration used in most deployments. The sensor type, depth and when deployed are shown in Tables 2 and 3 and the sensor serial numbers in Part 2 Tables 6 and 7.

2. Buoy: The buoy, designed for the GLOBEC application, used a Gilman Corp. Surlyn foam flotation collar (Fig. 3) around an aluminum instrument well with tower and base. The tower carried meteorological sensors, antennas, solar panels and a guard light. The buoy was constructed from 5400 series aluminum for its low corrosion properties. After being exposed to the environment for about 6 years (either deployed on Georges Bank or sitting on the WHOI dock), the two buoys were disassembled, cleaned, checked and repainted. No corrosion was found on either buoy and no repairs were made for subsequent deployment in GoMOOS (the Gulf of Maine Ocean Observing System).

Power for many sensors and the data system was supplied by four 20-Watt Solarex or Siemens solar panels on the tower that charged three 40-ampere-hour 12-V Powersonics gel cell batteries through Specialty Concepts, Inc. shunt regulators. The solar panels were set at an angle of the latitude plus 10° as suggested by solar power suppliers, but this angle is not that critical. The power system was divided into three parallel sections with diodes to prevent a failure in one from discharging the other. The solar panels were mounted in aluminum angle frames that protected the solar panels from damage. Also, a sensor guard ring was attached to the top of the tower, and the solar panels were mounted within a line from the guard ring down to the Surlyn foam flotation collar for protection. The only solar panels damaged during GLOBEC were during a recovery operation when the buoy was dragged up the side of a vessel where a bracket was welded, and when a buoy was being moved across deck and bumped a deck cleat.

To aid in locating the buoy should it break loose, the data system used an ARGOS transmitter that also transmitted system status and battery voltage separate of the main GOES data telemetry link. This provided additional information on system operation if the GOES link failed. In addition, a second ARGOS transmitter on separate batteries provided position information independent of the main data system and solar-charged batteries, should the main data system fail and discharge the solar-charged batteries.

The buoy data system was constructed from Synergetics 3400 series modules and consisted of controller, a general purpose programmable sensor interface, GOES and ARGOS transmitters, and a custom-built PCMCIA recorder based on a Triangle Data System TDS2020 controller for primary data storage. The ARGOS and GOES telemetry units used the same antenna with an RF switch to connect the antenna to the 40-Watt GOES transmitter for the 30 or so seconds required for the GOES transmission every three hours. The remaining time, the

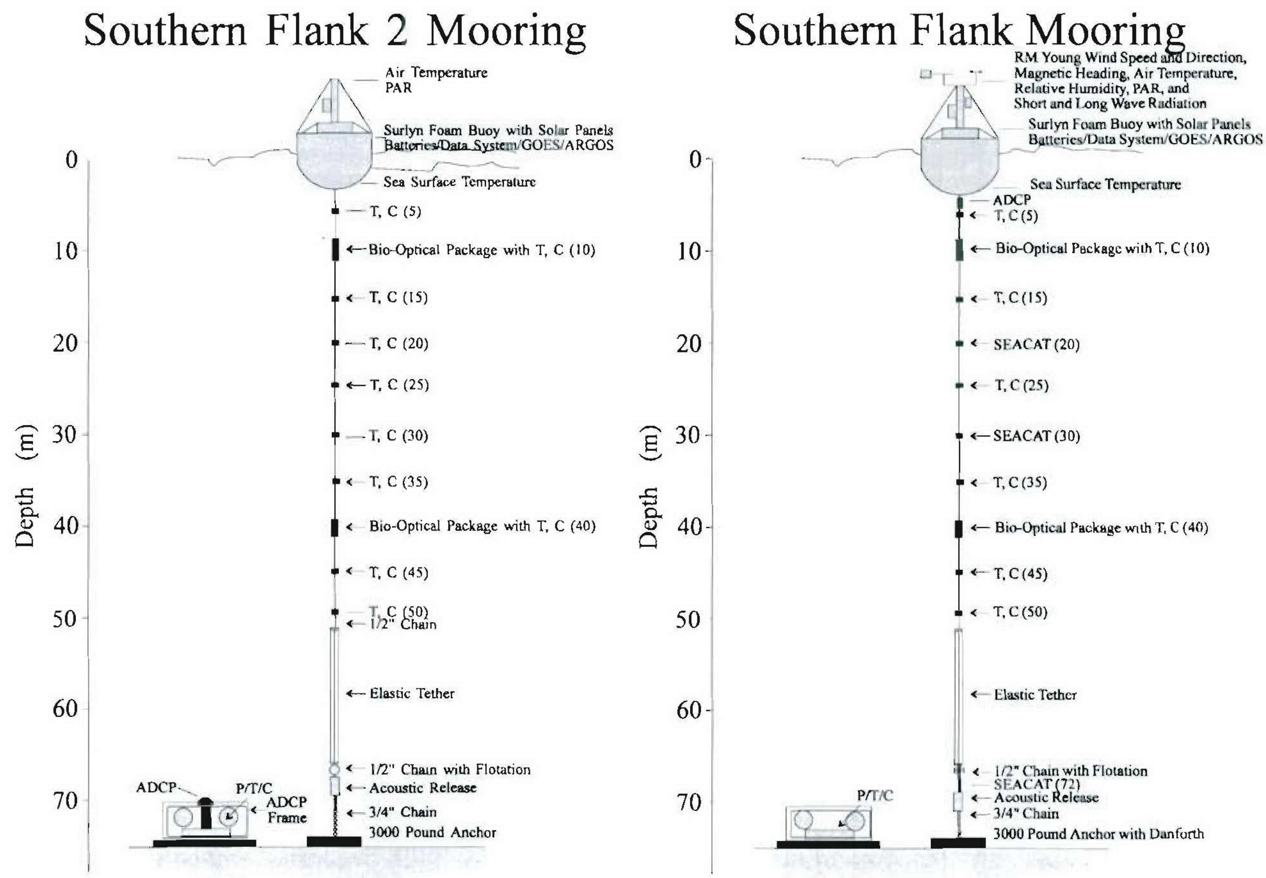


Figure 2. Southern Flank (and Northeast Peak) Mooring Configurations. The fall 1994 to fall 1995 (year one) configuration is shown at left with the ADCP separate, and all sensors powered, data collected and telemetered from the buoy. The right shows the default configuration for years two, three, four and five and for the Northeast Peak mooring (but without the bottom P/T/C instrument and full meteorological suite).

antenna was connected to the data system's ARGOS transmitter. The primary data storage was in the buoy, but the GOES system was used as the first backup of data. All data stored on the buoy were transmitted to shore via GOES, and when received properly provided 100% data recovery. For redundancy, to make sure that most of the data was received on shore, the system was programmed to transmit the last six hours of data every three hours. The data system's ARGOS was a second backup data link for limited diagnostic data, but was primarily used to check on the location of the mooring should it break loose. However, during 1999, the ARGOS link was also used to telemeter temperature and salinity information to identify cold, fresh Scotian Shelf crossover events to enable ship surveys to respond.

3. Meteorological Sensors: The Southern Flank buoy had a suite of meteorological sensors (Fig. 3) consisting of an R.M. Young anemometer, KVH compass (mounted near the center of mass of the buoy to minimize acceleration effects), a Rotronics air temperature and relative humidity sensor, Eppley long- and short-wave radiation and LiCor PAR (Photosynthetically Active Radiation) sensors. The meteorology sensors were provided and calibrated by Richard Payne of the Upper Ocean Process Group at WHOI. The data system measured the wind velocity components relative to the buoy at 1 Hz, then every minute powered up the compass and rotated

the 1-minute averaged velocity components relative to the buoy, into velocity components relative to magnetic north and averaged these components to hourly values. Also, the wind speed was averaged to hourly values, and the gust (the maximum observed speed during the

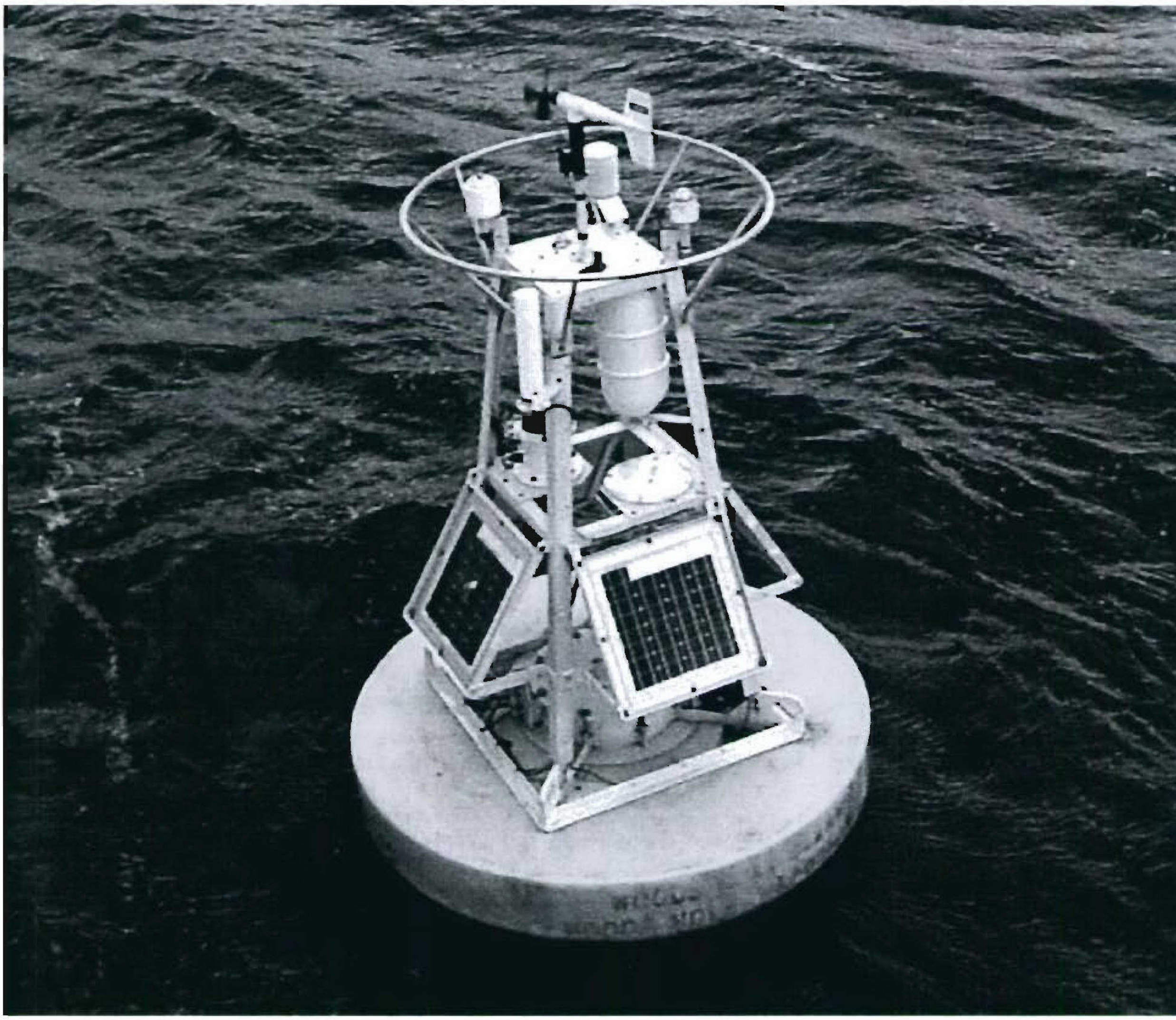


Figure 3. The Southern Flank buoy in Oct 97. The yellow Surlyn flotation collar surrounds the aluminum electronics well. The four 20-Watt solar panels are mounted on the tower and supply power for sensors and data system. The flat white antenna above the solar panels is an ARGOS beacon that is separate from the data system for tracking the buoy's position. The guard light is seen in the middle of the tower, partially hidden by the data system's GOES/ARGOS antenna (the white cylinder). The meteorological sensors can be seen on the top of the buoy protected by an aluminum guard ring. The R.M Young anemometer is mounted in the center of the buoy. Behind it can be seen a Gill radiation shield with the Rotronics air temperature and relative humidity sensor. On the right is the short-wave radiation sensor, and the left the long-wave radiation sensor. The small dark sensor on the top plate of the tower is the LiCor cosine PAR sensor. The compass is mounted in the electronics well near the center of mass of the buoy. The well also houses the batteries, shunt regulators for the solar power system, and the Synergetics data system with GOES and ARGOS transmitters.

hour) recorded. The Rotronics Model MP-100 air temperature and relative humidity sensor was mounted in a Gill radiation shield, sampled once per minute and averaged to hourly values. The radiation sensors (PAR, short-wave and long-wave radiation) were sampled at 10-second intervals and averaged to hourly values. The PAR sensor was a LiCor UWQ cosine collector mounted on the tower to measure the solar incoming radiation to compare with the 4π scalar sensor on the bio-optical packages at 10-m and 40-m depths. The short-wave radiation sensor was an Eppley Labs Model 8-48 Black and White Pyranometer, and the long-wave radiation sensor was an Eppley Labs Model PIR precision infrared radiometer.

4. Water Velocity Profiles: Water velocity profiles were measured with a 300-kHz RD Instruments Workhorse ADCP (Acoustic Doppler Current Profiler) mounted at the top of the mooring in a downward looking configuration (Fig. 4). The ADCP pinged at as high a rate as possible with the power available in the ADCP with auxiliary battery pack – 900 pings at 4-second intervals so that the expected uncertainty in the velocity measurement was less that 0.5 cm/sec. The 1-hour (or sometimes 0.5 hour) averaged horizontal velocities were measured in 1-m vertical bins from about 8-m depth to about 10 m above bottom. The loss at the top was due to blanking to remove transducer ringing, and the loss at the bottom was due to sidelobe reflection from the direct downward path to the bottom. The amplitude of the backscattered signal was also recorded in the 1-meter bins and used to monitor the time and depth changes in backscattered signal (related to biological scatterers in the water column). The ADCP also "saw" the instrumentation along the mooring line as side-lobe reflection contamination of the records. This was not apparent in short records (1 week), but becomes obvious with 6-month long record averages. The amplitude of the backscattered signal was increased and the Doppler velocities decreased at the depths of the sensors. The decreased velocity estimate is because the signal reflected from the stationary sensors has zero Doppler shift and biases the velocity estimate toward zero.

5. Temperature and Salinity: Water properties were measured with Sea-Bird Electronics temperature and conductivity sensors, SEACATs and MicroCATs (Fig. 5). The SBE-3 temperature and SBE-4 conductivity sensors were powered from the buoy (under software control of the data system) and returned FM signals to the buoy for digitization, compression, storage and telemetry. These sensors were mounted at 5-, 15-, 25-, 35-, 45- and 50-m depths (Fig. 2 , Table 2). No sensors could be mounted in the region of the compliant elastic tethers. SEACATs (SBE-16) were mounted at 20 and 30 m depth and bio-optical packages at 10 and 40 m depth. A SEACAT (SBE-16) or MicroCAT (SBE-37) was mounted about 72-m depth (4 m above bottom) to measure near-bottom water properties. The SEACATs were equipped with Lithium battery packs so that the sampling interval could be set to two minutes and last an entire year. During some high stratification times, the SEACATs were set to sample at 1-minute intervals to resolve the internal solitary wave activity (Part 3 section D and Figure 71). When a MicroCAT replaced the bottom SEACAT at 72 m, its sample interval was set to 5 minutes.

To reduce biofouling effects on the conductivity (and salinity) measurements, standard Sea-Bird tributyltin antifouling cylinders were placed on each end of the conductivity cells of each sensor for each deployment (Fig. 5). The sensor would come back fouled, but the inside of the conductivity cell was generally quite shinny and clean. However, there was still some drift in the conductivity records and each record was checked at the start and end relative to calibration CTD profiles, and against neighboring sensors for the final data set. Every temperature or

Tables 2: Southern Flank Science Mooring, Sensor, Depth and when Deployed

Depth	Sensor	Make	SF1	SF2	SF3	SF4	SF5	SF6	SF7	SF8	SF9	SFA	SFB
-3 m	Air Temperature	Rotronics	X	X	X	X	X	X	X	X	X	X	X
	Relative Humidity	Rotronics			X	X	X	X	X	X	X	X	X
	Wind Speed & Dir	RMYoung			X	X	X	X	X	X	X	X	X
	PAR	LiCor UWQ	X	X	X	X	X	X	X	X	X	X	X
	Short Wave Rad	Eppley 8-48			X	X	X	X	X	X	X	X	X
	Long Wave Rad	Eppley PIR			X	X	X	X	X	X	X	X	X
1 m	Temperature	SBE-3	X	X	X	X	X	X	X	X	X	X	X
3 m	ADCP	Workhorse			X	X	X	X	X	X	X	X	X
5 m	Temp/Cond	SBE-3/4	X	X	X	X	X	X	X	X	X	X	X
10 m	Biop	See note 1	X	X	X	X	X	X	X	X	X	X	X
15 m	Temp/Cond	SBE-3/4	X	X	X	X	X	X		X		X	X
20 m	Temp/Cond	SBE-3/4 or SEACAT	X	X	X	X	X	X	X	X	X	X	X
25 m	Temp/Cond	SBE-3/4	X	X	X	X	X	X		X		X	X
30 m	Temp/Cond	SBE-3/4 or SEACAT	X	X	X	X	X	X	X	X	X	X	X
35 m	Temp/Cond	SBE-3/4	X	X	X	X	X	X		X		X	X
40 m	Temp/Cond	See note 1	X	X	X	X	X	X	X	X	X	X	X
45 m	Temp/Cond	SBE-3/4	X	X	X	X	X	X		X		X	X
50 m	Temp/Cond	SBE-3/4	X	X	X	X	X	X	X	X	X	X	X
72 m	Temp/Cond	SEACAT or MicroCAT			X	X	X	X	X	X	X	X	X
76 m	Bottom Pressure	SBE-26				X			X	X	X	X	X

1. Bio-optical package with recorder Sea-Bird Temperature and conductivity, SeaTech fluorometer and 25 cm pathlength transmissometer and LiCor SPQA PAR.

Table 3: Southern Flank Guard Buoy Sensors

Depth	Sensor	Make	SG1	SG2	SG3	SG4	SG5	SG6	SG7	SG8	SG9	SGA	SGB
1 m	Temperature	PMEL		X									
10 m	Temperature	PMEL		X									
20 m	Temperature	PMEL		X									
50 m	Temperature	PMEL		X									

Tables 4: Crest Science Mooring, Sensor, Depth and when Deployed

Depth	Sensor	Make	SF1	SF2	SF3	SF4	SF5	SF6	SF7	SF8	SF9	SFA	SFB
-3 m	Air Temperature	Rotronics	X	X									
	Load Cell	LiCor UWQ	X										
1 m	Temp/Cond	SBE-3 / 4	X	X									
10 m	Biop	See note 1		X									

1. Bio-Optical package with recorder Sea-Bird Temperature and conductivity, SeaTech fluorometer and 25 cm pathlength transmissometer and LiCor SPQA PAR.

Tables 5: Northeast Peak Science Mooring, Sensor, Depth and when Deployed

Depth	Sensor	Make	SF1	SF2	SF3	SF4	SF5	SF6	SF7	SF8	SF9	SFA	SFB
-3 m	Air Temperature	Rotronics			X	X	X	X			X	X	X
	PAR	LiCor UWQ			X	X	X	X			X	X	X
1 m	Temperature	SBE-3			X	X	X	X			X	X	X
3 m	ADCP	Workhorse			X		X	X			X	X	X
5 m	Temp/Cond	SBE-3/4			X						X	X	X
10 m	Biop	See note 1			X	X	X	X			X	X	X
15 m	Temp/Cond	SBE-3/4			X						X	X	X
20 m	Temp/Cond	SBE-3/4 or SEACAT			X	X	X	X			X	X	X
25 m	Temp/Cond	SBE-3/4			X								
30 m	Temp/Cond	SBE-3/4 or SEACAT			X	X	X	X			X	X	X
35 m	Temp/Cond	SBE-3/4			X								
40 m	Temp/Cond	See note 2			X	X	X	X			X	X	X
45 m	Temp/Cond	SBE-3/4			X								
50 m	Temp/Cond	SBE-3/4			X	X	X	X			X	X	X
72 m	Temp/Cond	SEACAT or MicroCAT			X	X	X	X			X	X	X

1. Bio-optical package with recorder Sea-Bird Temperature and conductivity, SeaTech fluorometer and 25 cm path-length transmissometer and LiCor SPQA PAR.
2. Switched between full Bio-optical packages (see Note 1) or just Temperature and Conductivity.

conductivity sensor was sent back to Sea-Bird Electronics every fall for cleaning, a check-up and calibration. The conductivity cell electrodes were also replatenized each year.

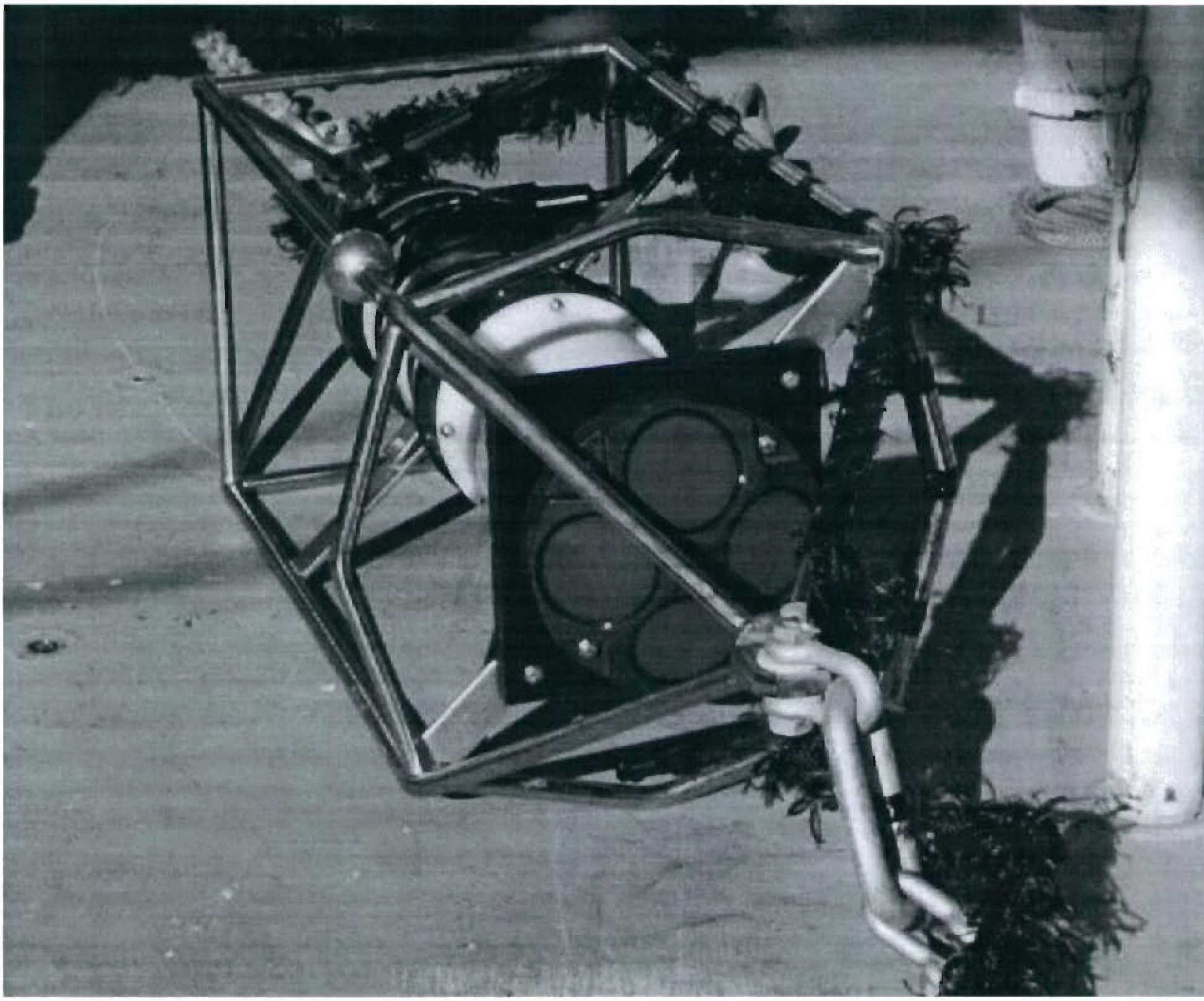


Figure 4. 300-kHz RD Instruments Workhorse ADCP mounted in a downward looking configuration in an in-line frame with auxiliary battery pack. The frame was connected to the buoy with 1 m of chain to decouple the buoy tilting motion from the current observations. The mooring cable (Kevlar strength member with electrical cables and poly anti-strumming hair is the black cable taped to the ADCP frame.

6. Bio-Optical Properties: To measure in-situ chlorophyll-a concentrations, particle concentration, and PAR (the light available to drive photosynthesis), internally powered and recording bio-optical packages were constructed and deployed at 10- and 40-m depths. The 10-m package sampled the upper mixed layer and the 40-m package sampled bottom layer below the pycnocline. Each package had an SBE-3 temperature and SBE-4 conductivity sensor, a Sea Tech 25-cm path-length transmissometer, a Sea Point Optical Backscattering Sensor (on the Southern Flank 10-m package only), a Sea Tech chlorophyll-a fluorometer, and a LiCor scalar (4π steradians) PAR sensor. A low-power integrated sub-processor collected the PAR data and transferred the averaged results to the recorder at the end of each sample interval. The instruments (Fig. 6) were self-contained with batteries and a custom designed data system. The

sensors were powered and sampled at 16 times per hour (3.75 minutes) and were capable of transmitting all data up the electromechanical cable. However, the buoy's data telemetry system was not capable of handling the extra data so all data were logged internally on 2 MB or 4 MB PCMCIA Flash in DOS readable files. To reduce bio-fouling (the main factor controlling data quality), poison tubes with tributyltin antifouling compound were put on the ends of the conductivity cell, and around the transmissometer and fluorometer windows before each deployment. However, as the experiment progressed, it became obvious that the best protection against antifouling (to obtain long record lengths) was a new, clean optical window. We typically obtained 90- to 120-day records with clean windows over winter and springtime periods (see Part 2, Yearly Data Report and Part 3, Data Summary).

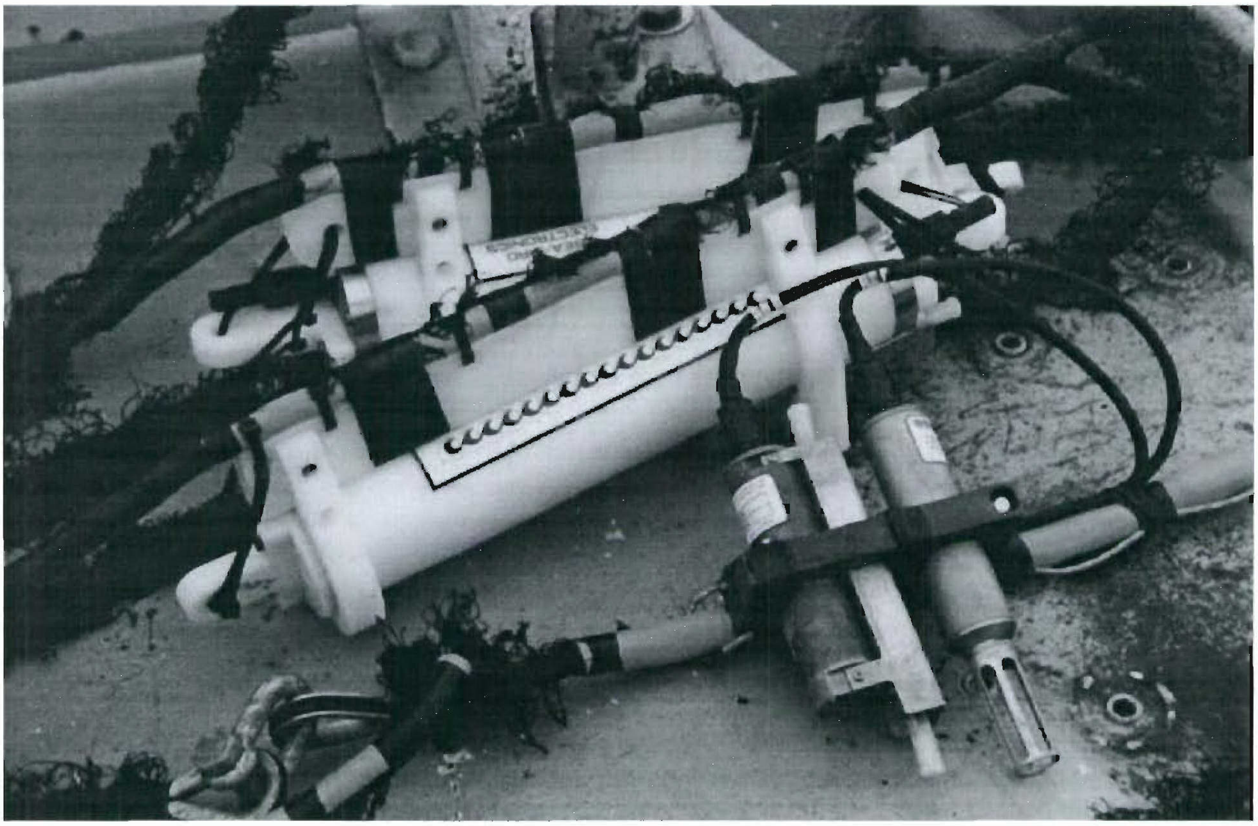


Figure 5. Two Sea-Bird SEACATs (top) and SBE-3 temperature and SBE-4 conductivity sensors (bottom). The temperature and conductivity sensors are mounted perpendicular to the electromechanical mooring cable in a PVC clamp on a length of garden hose that was split and put around the electromechanical cable to avoid sharp bending and chafing of the electrical or strength member. The horizontal orientation provides optimum flushing of the sensors. The SEACATs are mounted parallel with the mooring cable and tie wrapped and taped to the cable. The white tubes on the conductivity sensors are antifouling tubes to reduce biological induced drift in the conductivity observations.

7. Bottom Pressure: Initially, bottom pressure measurements were planned for the bottom mounted ADCP (Kery and Irish, 1996), but the new RD Instruments broadband ADCPs (pre-Workhorse configuration) did not have this feature, so some older Sea Data systems were brought back into service to record pressure from Paroscientific sensors. The new broadband ADCPs did not work for the first two deployments, and were replaced by Workhorse ADCPs

mounted on the mooring in a downward looking configuration so that we could monitor their operation. The Workhorse ADCPs continued to work well for the rest of the deployment, but the bottom mounted broadband ADCPs still had problems stopping. The bottom pressure instrument also had recorder problems, and partial records were returned in deployment 3 and 5 and were abandoned in favor of a Sea-Bird Model 26 SeaGuage Wave and Tide Gauge (borrowed from Dr. Steve Lentz. WHOI). This configuration worked well for the rest of the program. It was attached to a bottom buoyant frame (Fig. 7) with acoustic release to drop the anchor. The instrument was deployed between the Southern Flank science mooring and a guard buoy (see Table 1).

A conductivity sensor was also mounted on this package, but in a horizontal configuration. It was discovered that this sensor easily became contaminated with sediment that settled out in the conductivity cell, and reduced the conductivity measurement. This sediment was sometimes "blown" out in a high current event, and the conductivity returned to similar values as that seen on the 72-m SEACAT or MicroCAT. These sensors were mounted with the cell vertical so that sediment would not settle out in them. The horizontal configuration sounded good for best flushing, but during the final year, the conductivity sensor was mounted at an angle on one of the instrument frame legs, and this configuration worked well.

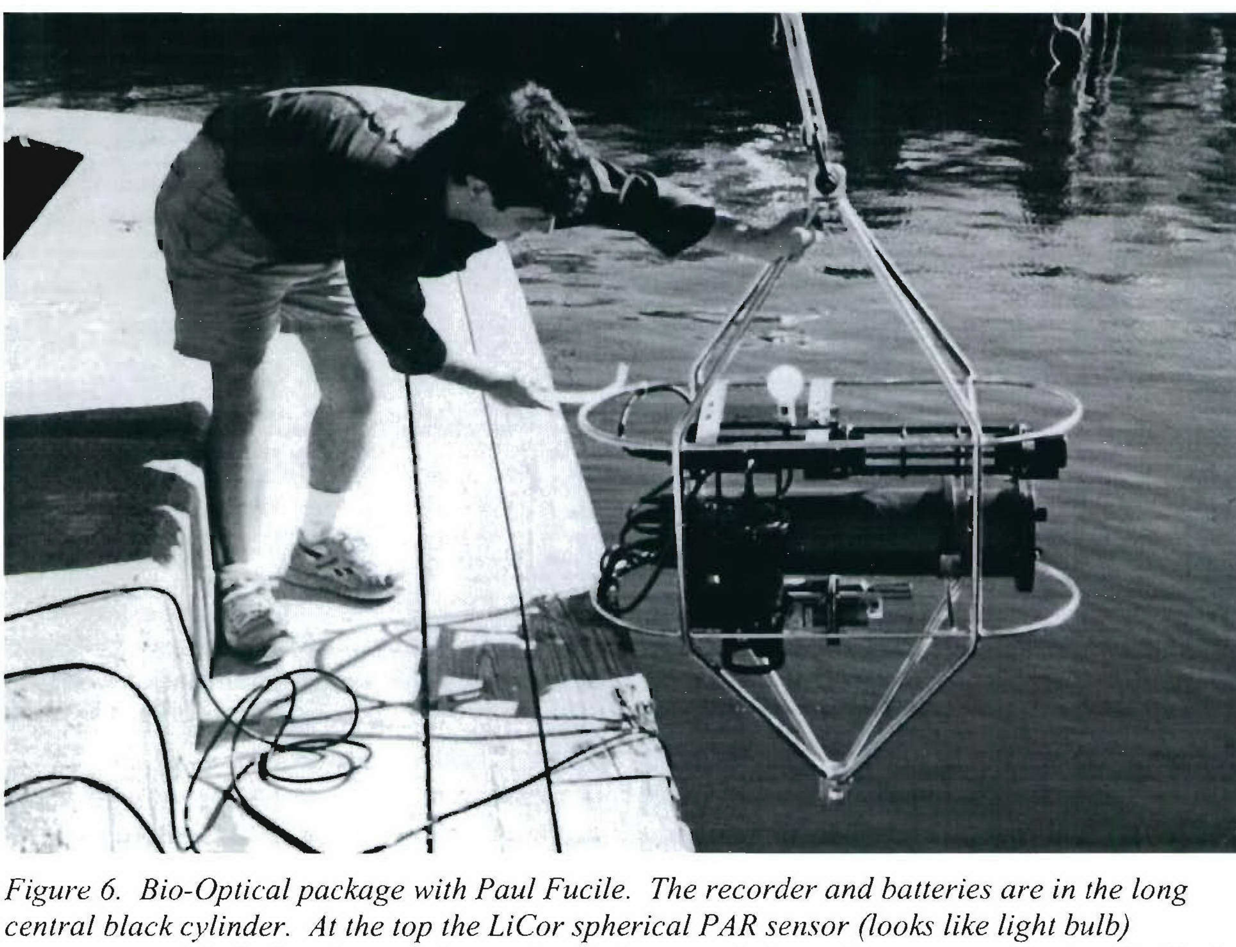


Figure 6. Bio-Optical package with Paul Fucile. The recorder and batteries are in the long central black cylinder. At the top the LiCor spherical PAR sensor (looks like light bulb) measures total light for photosynthesis. Just below it and above the pressure case is a SeaTech 25-cm path-length transmissometer. At the bottom left is a SeaTech chlorophyll-a fluorometer, and in the center, Sea-Bird temperature and conductivity sensors.

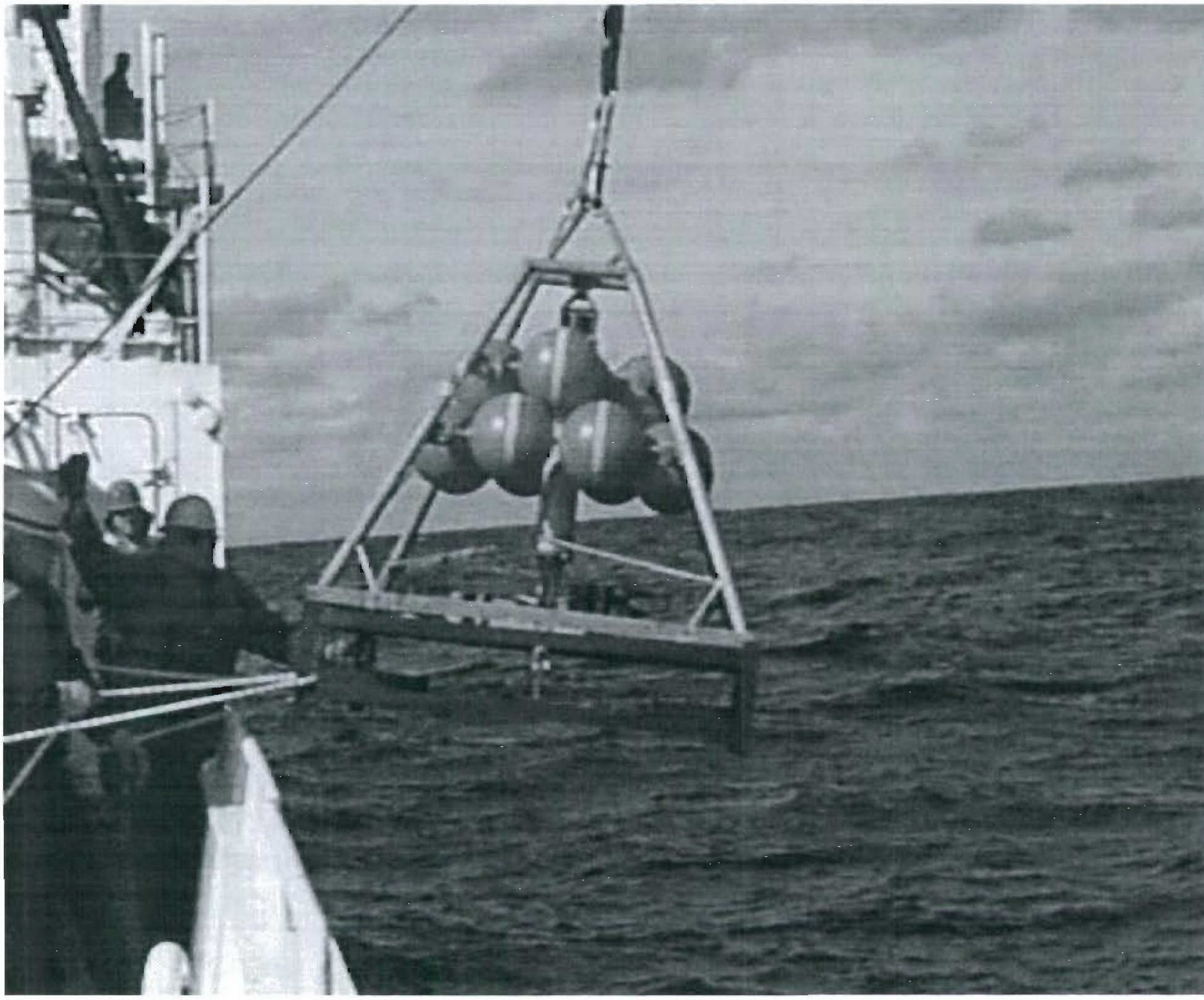


Figure 7. Bottom pressure instrument with Sea-Bird bottom pressure recorder being launched from the R/V ENDEAVOR. The plastic orange flotation spheres return the top portion of the instrument to the surface for recovery. The acoustic release (yellow vertical canister in center) releases the anchor (bottom iron frame) allowing the flotation to bring the instrument (horizontal blue cylinder) and aluminum frame to the surface for recovery.

B. Crest Mooring:

The Crest site was selected to be in the well-mixed region on the top of Georges Bank. The site was selected directly up-bank from the Southern Flank site so that they would form a cross-shelf array. The top of Georges Bank on the Southern Flank side, shallower than 50 m, has large sand/gravel ridges. The transition between the smooth deeper topography and shallower ridge topography is abrupt and located at about 55-m depth, which is about the location of the tidally mixed front in the summer. In the region of the Crest mooring site (43-m depth), the ridges are about 8 to 15 m in height with 500 to 800 m wavelength. These ridges have a strong effect on the current flow patterns in the region since they are up to 1/3 the water depth and help mix the Crest region from top to bottom. The Crest mooring site was selected in as deep water as possible to be inside the tidally-mixed front so that it would represent the well-mixed and biologically-active water at the Crest of the bank, and yet have the deepest water to reduce

environmental forcing (tidal velocity and waves) on the mooring components. The Minerals Management Service/EG&G program on Georges Bank in the early 1980's had difficulty keeping standard chain catenary moorings in place there, so we decided to use the elastic tether technology (see below) to improve the probability of making moored observations there.

The Crest mooring had two basic configurations (Fig. 8 and Table 4). The buoy (Fig. 9) was a reworked steel float as used in the Gulf of Maine (Irish et al., 1987, Irish et al., 1992 and Wood and Irish, 1987). For the first six-month deployment, only surface sensors were put on the buoy because we were unsure of the survivability of the system in the harsh environmental conditions found on the Crest of Georges Bank. A load cell was placed between the buoy and mooring cable to monitor the tension in the mooring (the data system calculated the mean and standard deviation within the hour sample). This was used to evaluate the elastic tether technology (see below and Paul, et al., 1999). The second six-month deployment had a bio-optical package at 10 m depth to monitor surface to 10-m stratification, and to get an estimate of the bio-optical variability. This mooring and its sensors survived for the first year, but was eliminated in favor of the Northeast Peak mooring with GLOBEC reallocation of priorities and resources.

C. Northeast Peak Mooring:

The Northeast Peak site was selected to be on the same depth contour and upstream of the Southern Flank Site. It was located in the region where cod and haddock spawn to observe the water properties and flow in this region. The Northeast Peak mooring was initially designed to be the same as the Southern Flank mooring (Fig. 2), but practicalities, mooring damage and program reallocations reduced the number of sensors and deployments at this site. Both a second foam buoy similar to the SF mooring (Fig. 2) and the steel buoy used at the Crest (Fig. 9) were used at the Northeast Peak site. The sensor allocation (Table 5) was also reduced during winter mixed water times to allow a maximum number of sensors to be deployed at the Southern Flank site (Table 2).

III. ELASTIC TETHER MOORINGTECHNOLOGY

The mooring cables for the data buoys were constructed by Cortland Cable Co. and consisted of a Kevlar strength member with electrical cables helixed around it to allow for tension member stretch without breaking the electrical conductors. The conductors were broken out of the mooring cable at each temperature-conductivity sensor depth (Fig. 5) constructed by Cortland Cable. A key part of these moorings was the compliant elastic component between the instrumented mooring cable and the anchor. A mooring needs compliance to allow the buoy to move with the currents, tides and waves. Traditionally, this compliance has been supplied by a length of heavy mooring chain on the bottom. The buoy lifts the required amount of chain off the bottom to move with the waves, tides and currents. However, with time the chain becomes worn, and heavier mooring hardware and larger buoys are required to use this technology (e.g. the Coast Guard navigational buoys and the National Data Buoy Center's discus and Nomad buoys). In GLOBEC, we adopted the use of the elastic tethers that keeps the mooring cable taut and off the bottom, and allows the use of lighter weight hardware, mooring cable and buoy. This approach has worked well in the Gulf of Maine (Wood and Irish, 1987), in Massachusetts Bay (Irish, et al. 1992) and in GLOBEC on Georges Bank (Irish and Kery, 1996, Irish, 1997 and 2000, and Paul, et al., 1999).

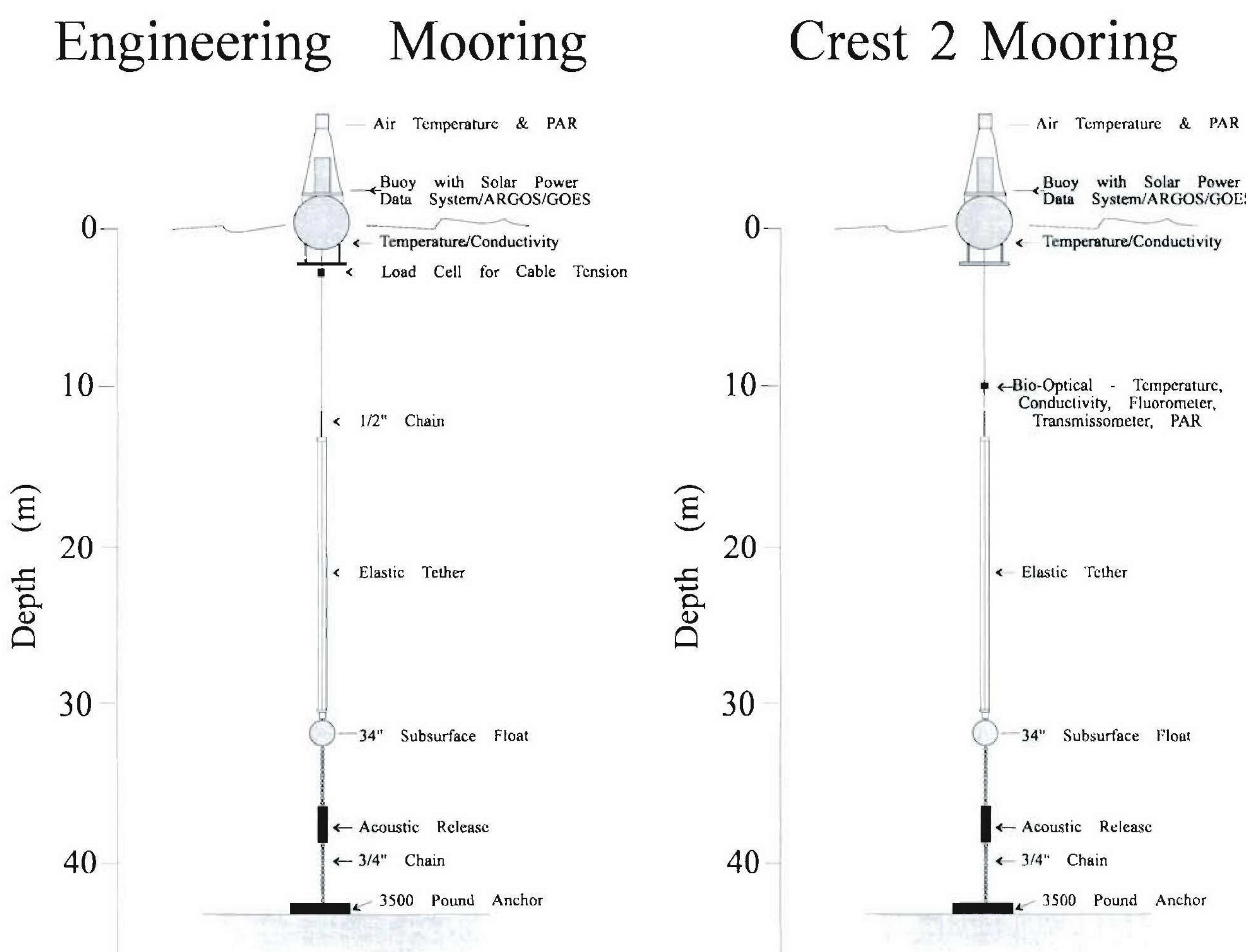


Figure 8. Crest Mooring configurations. The winter 1994-95 engineering test configuration is shown at left with the load cell at the bottom of the buoy at the mooring cable attachment point. The second deployment in summer and fall 1995 is shown at right with the bio-optical package at 10 meters depth.

The compliant tethers keep the mooring watch circle small, so there is reduced chance of fishing gear entanglement as the anchor is nearly under the buoy. The elastic elements supply a somewhat constant (e.g. tensions varying from 500 to 1,200 lbs at the Southern Flank site) downward tension in the mooring yet still supply the compliance to allow the buoy to ride with the waves. This reduces wave damage and provides a better riding platform for scientific observations. No buoy or sensor on these moorings was damaged by waves during GLOBEC Georges Bank deployments. However, the weakness of the tethers and the electromechanical cable is their susceptibility to being cut by fishing activities. This occurred several times as can be seen by the gaps in the data presented in Part 2 and Part 3. The acoustic release and subsurface float enabled the retrieval of the bottom portion of the mooring with sensors in case of loss of the surface float. This allowed the mooring to be redeployed with the same sensors after replacement of the tethers or electromechanical cable.

Each elastic tether element (Fig. 10) must be terminated so there is minimal stress concentration in the rubber material at the splice. The splices were done by Buoy Technology

Inc. of Concord, NH who specializes in elastic tethers (Wyman, 1982). Also, the tether must be kept from twisting so a swivel was placed between the tether and electromechanical cable. One tether assembly on the Northeast Peak mooring probably broke because a bad swivel was used, and the tether could not supply the compliance required by the strong tidal currents and waves. With the tethers in the mooring, the wear on the mooring components was substantially reduced. During the five years of GLOBEC, no wear was observed on any chain, shackles, etc. on the elastic tether moorings as compared with the nearby chain-catenary guard moorings (see below).

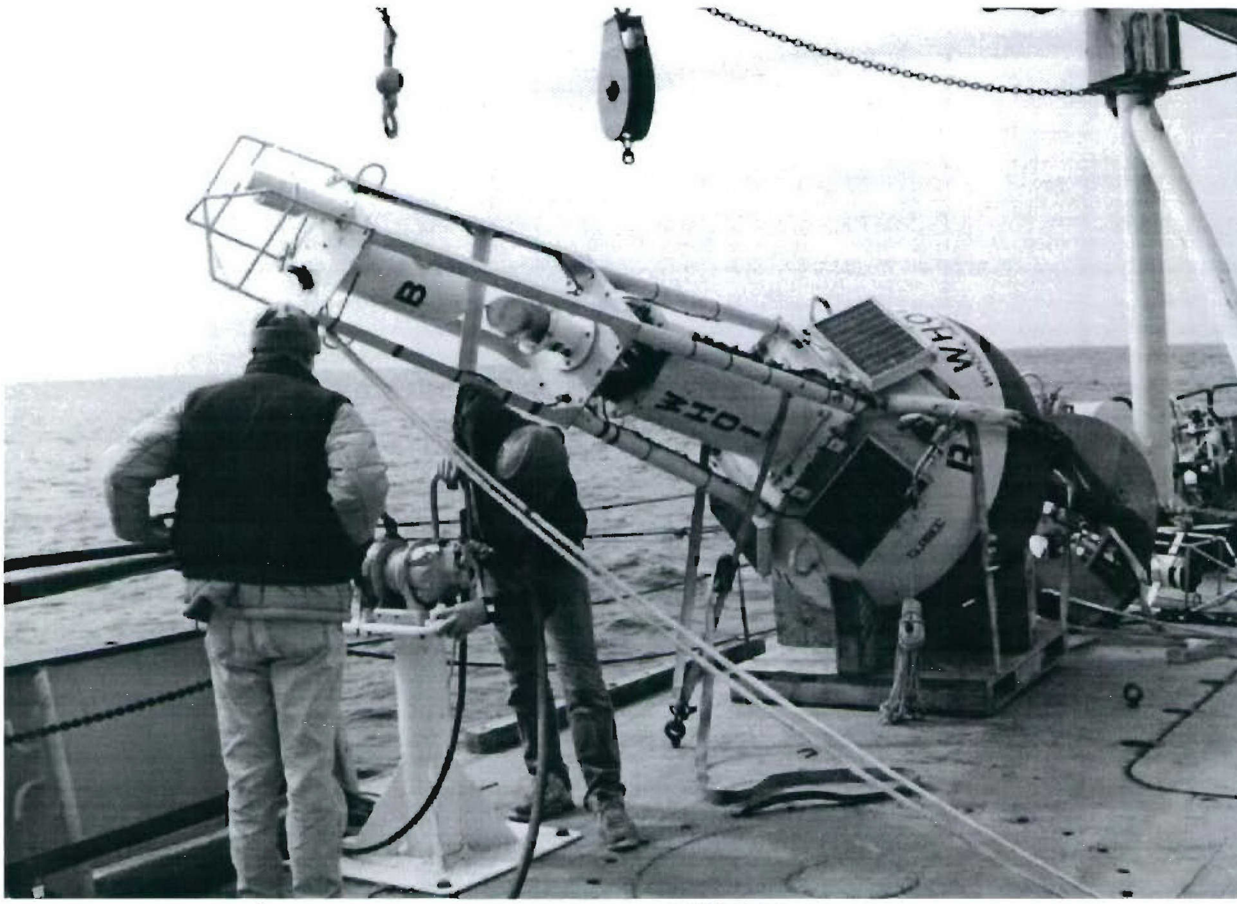


Figure 9 Crest and Northeast Peak buoy on deck of R/V KNORR prior to deployment in April 1997. The PAR sensor can be seen in the buoy tower top, with the Gill radiation shield partially hidden by the GOES/ARGOS antenna. The electronics and batteries are housed in the large cylinder in the base of the tower. Four 10-Watt solar panels provide power for the system. The sensors in the water are identical to the Southern Flank mooring.

As an engineering study of the elastic tether technology in harsh environments, the Crest mooring was deployed during the winter of 1994-95. This test proved the performance of elastic tethers as compliant elements in the mooring line to reduce stress and wear on the mooring components. To measure the tension in the mooring line (as a measure of the compliant elastic tether performance), a load cell was placed at the buoy attachment point and the statistics of the tension recorded (hourly mean and standard deviation of the tension). These observations showed that the average tension in the mooring was about 600 pounds, and did not exceed 1,400 pounds during winter storms (Paul, et al, 1999). The tension fluctuations were shown to be largely due to tidal and weather forced currents flowing over the Crest of Georges Bank.

Variations in tension due to the tidal velocities were several hundred pounds. The high frequency, wave-induced tension variations were a few hundred pounds and were not a significant factor in mooring tension. Therefore, the elastic tether moorings did improve mooring life due to reduced wear in the mooring components, they did provide better riding platforms for oceanographic and meteorological observations, and they allowed the Crest moorings to remain at the Crest of Georges Bank throughout the year.

The major weakness in the elastic technology is its susceptibility to being cut by fishermen, as was seen in the Southern Flank scientific mooring, which was cut five times, recovered and redeployed each time. Note that five chain-moored guard buoys were also cut loose in the during the Georges Bank program.

During 2 September 1996, the eye of hurricane Edouard passed within 17 km of the Georges Bank Southern Flank mooring. The mooring remained in place and recorded a unique look at the response of the Bank to a hurricane. The excess winds occurred over a 72-hour period with a 22-m/s peak speed and waves of 9.7-m significant height. Not only did the buoy and mooring survive, but no damage, wear, etc. was observed in the buoy or mooring components after recovery (Williams et al., 2001).

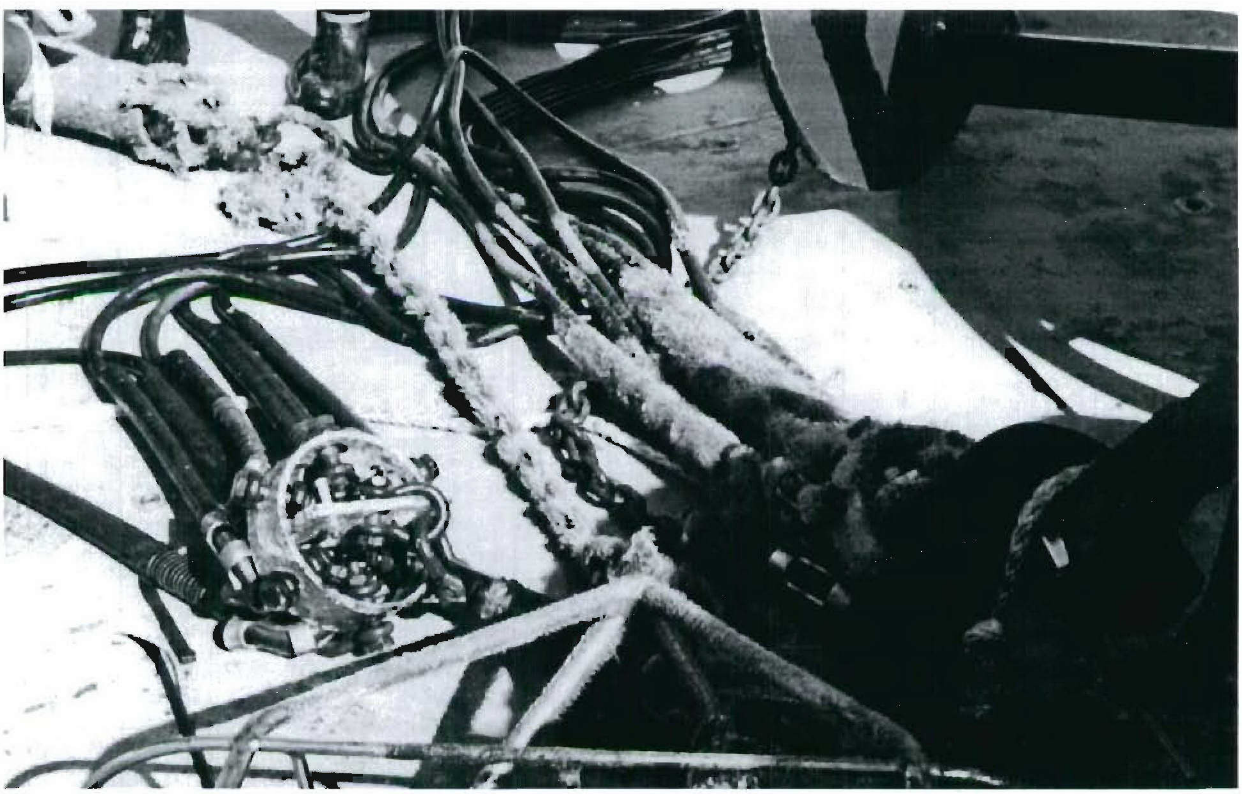


Figure 10. Compliant Elastic Tethers after recovery. The round bridle to which the six 10-m unstretched length elastics are shacked is seen in the left center of the picture. Six 1" diameter tethers are used to give the required stiffness, and the 10-m length provides the compliance to allow the mooring to move with the currents and tides, and still allow the buoy to move up and down with the waves. They provide about 500 lbs downward tension on the buoy.

The behavior of the elastic tether material was further studied in laboratory tests (Irish et al, 2005). A section of new Natsyn rubber, and a section of a used GLOBEC tether were

terminated and sent to Tension Member Technology for testing. The two tethers were stretched a mean elongation of 100, 150, 200 and 150%, and cycled around these mean elongations by 25 and 50%. The resulting tension-elongation results were reduced to elastic modulus version elongation curves. The results are non-linear (as expected for compliant materials), but showed a remarkable ability to return to original length and behavior. The modulus was found to be about 125 PSI for mean elongations around 100% with small oscillations around this mean – typical of a mooring with smaller waves. As the elongation increased, the modulus increased, especially at the point of maximum elongation. With elongations approaching 275%, the modulus increased to nearly 900 PSI. These results will aid in more refined mooring designs through use of such mooring analysis programs as WHOI Cable (Gobat et al, 1997).

The stability of the buoy with compliant elastic mooring was demonstrated (Fig. 11) when the light on a newly deployed buoy did not operate and the weather was calm enough (July 1999) to allow *in-situ* servicing. Scott Worrilow was able to stand on the buoy without it tipping significantly and easily replace the light.

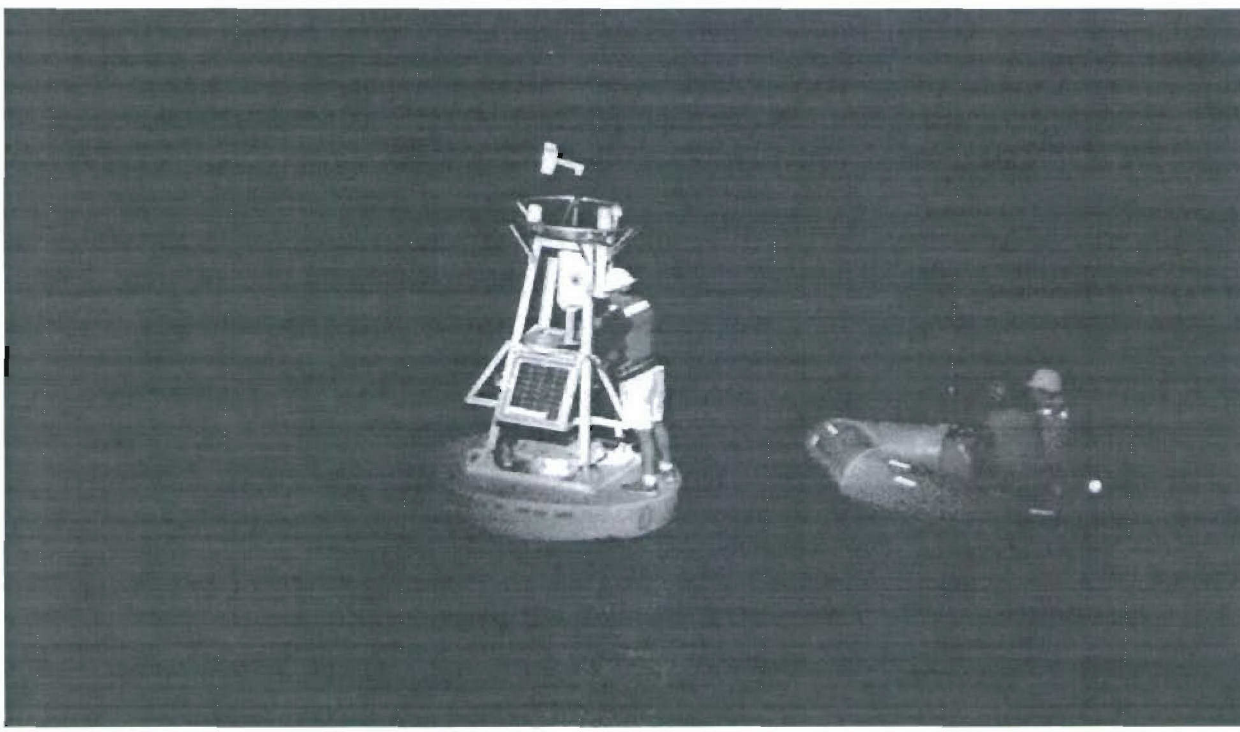
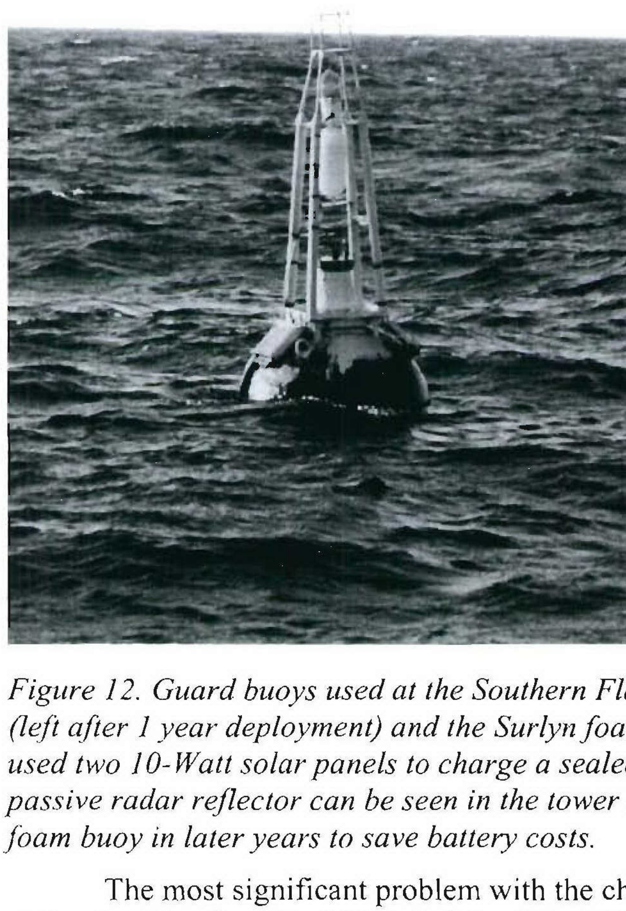


Figure 11. Scott Worrilow stands on the Southern Flank buoy one night in July 1999 in calm seas to repair the guard light. The buoy is stable because of the elastic tether constant downward force.

IV. GUARD BUOYS

To provide protection for the scientific moorings on the Southern Flank and Northeast Peak, two guard buoys were deployed, one on either side of each science mooring (aligned along the depth contours which draggers traverse). Either steel buoys or Surlyn foam buoys were used (Fig. 12) with a simple chain catenary mooring with ½" chain in the water column and ¾" chain on the bottom with a scope of 1.25. The anchor in both cases was about 2,500 lbs of steel. The moorings were deployed in the fall and recovered the next fall after about 11 months.

Unlike the elastic tether moorings, the chain catenary mooring hardware showed significant wear during the 11-month deployments. When newly recovered, the ¾" chain was shinny where it was moved about the anchor by the elliptical tidal currents on Georges Bank that effectively removed any galvanizing and corrosion products. The wear in the top of a retrieved anchor (Fig. 13 top right) showed this continual motion of the buoy and chain around the anchor. The shackles that caused the marks on the anchor, showed little wear, so this was not a significant factor in mooring life. The wear between links (Fig. 13 upper left) is minimal and not a significant problem. However, the pitting on the outside of the chain was the major source of wear and loss of strength in the chain. The chain in the figure was not the most corroded, but about normal or less than normal after 11 months on Georges Bank. Even more surprising was the loss of material on the ½" chain in the water column that had no abrasive effects of the bottom. The chain appears to be pitted, particularly at the highly stressed corners where the material was bent to form the links, showing significant corrosion and loss of material (Fig. 13 bottom right). This corrosion was the main loss of strength in the guard mooring chain, not wear and tear in the movement of the mooring with the waves.



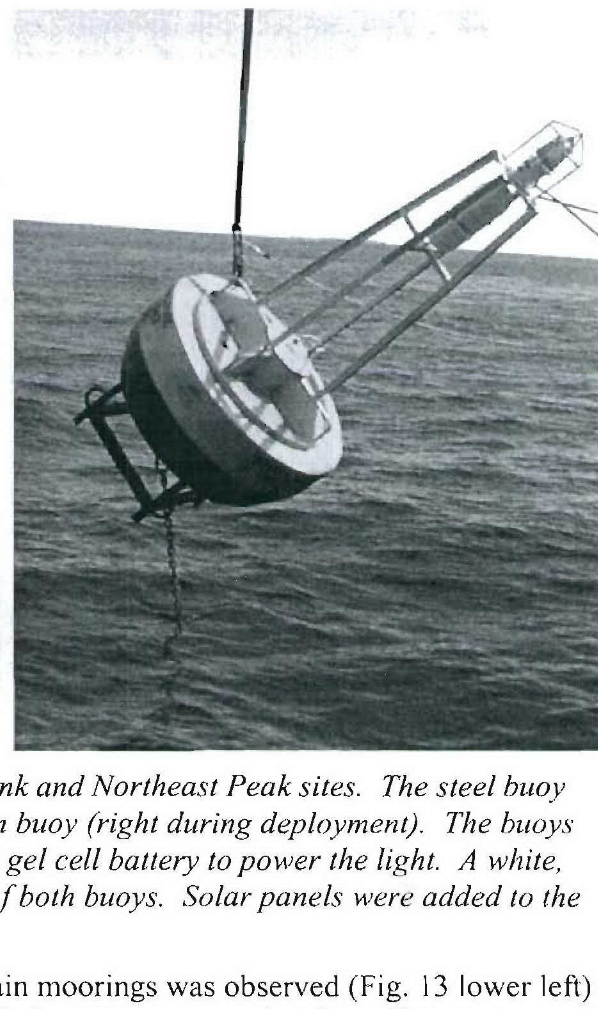


Figure 12. Guard buoys used at the Southern Flank and Northeast Peak sites. The steel buoy (left after 1 year deployment) and the Surlyn foam buoy (right during deployment). The buoys used two 10-Watt solar panels to charge a sealed gel cell battery to power the light. A white, passive radar reflector can be seen in the tower of both buoys. Solar panels were added to the foam buoy in later years to save battery costs.

The most significant problem with the chain moorings was observed (Fig. 13 lower left) at the shackle where the ¾" chain joined the ½" chain. This was comfortably off the bottom and out of the abrasion of the sand. However, the bolt in the chain shackle was not threaded all the way to the end past the cotter pin hole. The corrosion and movement of the nut wore the threads off the bolt, so that they no longer held the nut in place. In this case (the most extreme example

during GLOBEC) the nut is only held on by the cotter pin, and it was possible to remove the nut by hand, meaning that the cotter pin would be the only thing holding the mooring together. The movement of the bolt with the loose nut, wore the holes in the shackles to the point that it would

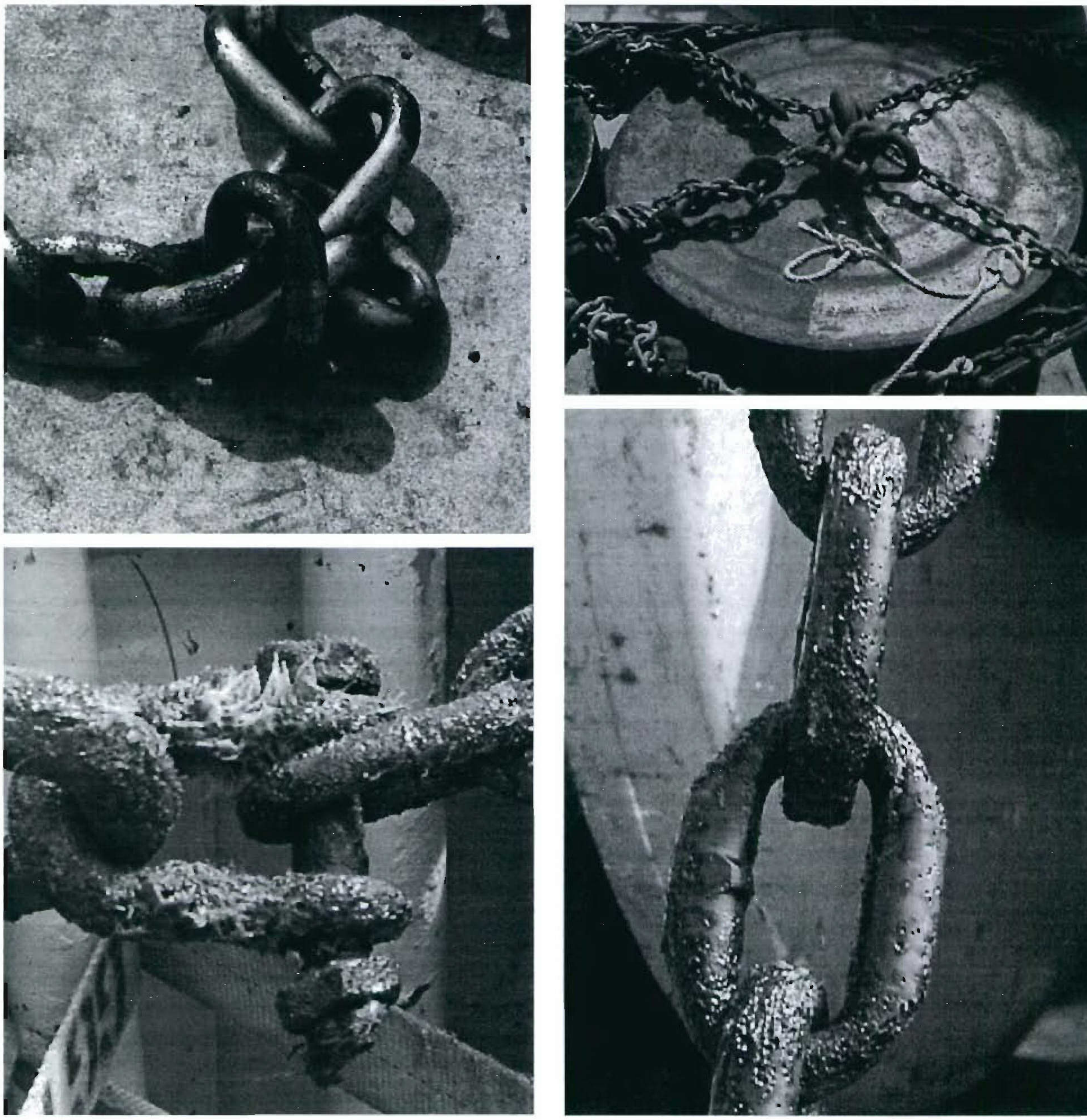


Figure 13. Guard buoy mooring chain. The ¾" chain (upper left) was shinny when recovered. The wear between links is minimal. A recovered anchor (upper right) shows wear due to the motion of the buoy around the anchor. The shackle between the ¾" and ½" chain (lower left), shows wear on the threads and the nut was only held on by the cotter pin. Finally, the ½" chain in the water column (lower right) showed pitting and corrosion on the outside of the links, losing up to ½ the material (and strength).

soon be possible to pass the cotter pin through the shackle, and allow the chain to separate. This was never observed to happen on shackle bolts with the threads extending all the way to the end.

V. SUMMARY

The Long-term Mooring Program used a mixture of new and old technologies to provide moored observations during the 5 years of the Northwest Atlantic Georges Bank GLOBEC field program. The elastic technology provided mooring compliance that worked well and withstood the environment on Georges Bank, but failed when cut by fishing operations. The individual temperature and conductivity sensors required an electromechanical cable that occasionally caused problems. Newer technology of sensors with inductive modems should allow improved flexibility in sensor placement and reliable telemetry of data to a buoy for relay to shore. The Workhorse broadband ADCPs proved reliable, but earlier broadband ADCPs were troublesome. The lightweight buoy systems proved reliable and rugged, and worked well. However, the Synergetics data systems that worked well over the past 15 years are dated and showed their inflexibility during GLOBEC. The guard buoys worked reliably, and survived their 11-month deployments on Georges Bank with only a few failures - probably associated with fishing activity. The buoys (both guard and science) showed evidence of being hit by boats, but no significant damage was done. One steel hull guard buoy that did break loose was sunk by the Coast Guard as a hazard to navigation and they reported it "heavily damaged," but we were unable to determine exactly what was damaged.

VI. ACKNOWKEDGEMENTS

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16. Abstract (Limit: 200 words)

As part of the U.S. GLOBEC Northwest Atlantic/Georges Bank program, moorings were deployed on Georges Bank as part of the broad-scale survey component to help measure the temporal variability of both physical and biological characteristics on the Bank. The array consisted of a primary mooring site on the Southern Flank which was maintained for the full 5-year duration of the field program, plus secondary moorings, with fewer sensors and of shorter duration, in the well-mixed water on the Crest and in the cod/haddock spawning region on the Northeast Peak. Temperature and conductivity (salinity) were measured at 5-m intervals, ADCP velocity profiles were obtained with 1-m vertical resolution, and bio-optical packages (measuring fluorescence, optical transmission and photosynthetically active radiation) were deployed at 10-m and 40-m depths. Bottom pressure was measured at the Southern Flank site. The buoy design, sensors and mooring configuration is presented and discussed below, and the data obtained is presented and discussed in an accompanying reports "U.S. GLOBEC Georges Bank Long-Term Moored Program: Part 2 - Yearly Data Summary and Report," and "U.S. GLOBEC Georges Bank Long-Term Moored Program: Part 3 - Data Summary."

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